The Land Information System

http://lis.gsfc.nasa.gov

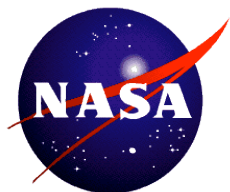**P. Houser** (GMU/CREW, formerly GSFC-614.3)
C. Peters-Lidard (GSFC-614.3)
S. Kumar (UMBC)
Y. Tian (UMBC)
J. Geiger (GSFC-587)
L. Lighty (GSFC-587)
S. Olden (GSFC-586)

Outline

1. Introduction/Background

2. LIS Overview

3. Impact: Missions and Science

4. Current and Potential Use

5. Software Description

6. Future Potential

7. Summary

Land Data Assimilation Systems: Motivation

## Quantification and prediction of land surface variability

- Surface temperature, soil moisture, and snow, significantly influence Earth system processes and predictability at multiple scales
- Improved knowledge of land conditions will promote better land resource management, natural hazard mitigation, and homeland security

Maturing of land surface observation and prediction tools:

- Observation: Forcing, storages(states), fluxes, and parameters.
- Simulation: Land process models (Hydrology, Biogeochemistry, etc.).
- Assimilation: Short-term state constraints.

"LDAS" concept:

Bring state-of-the-art tools together to _operationally_ obtain high quality land surface conditions and fluxes.
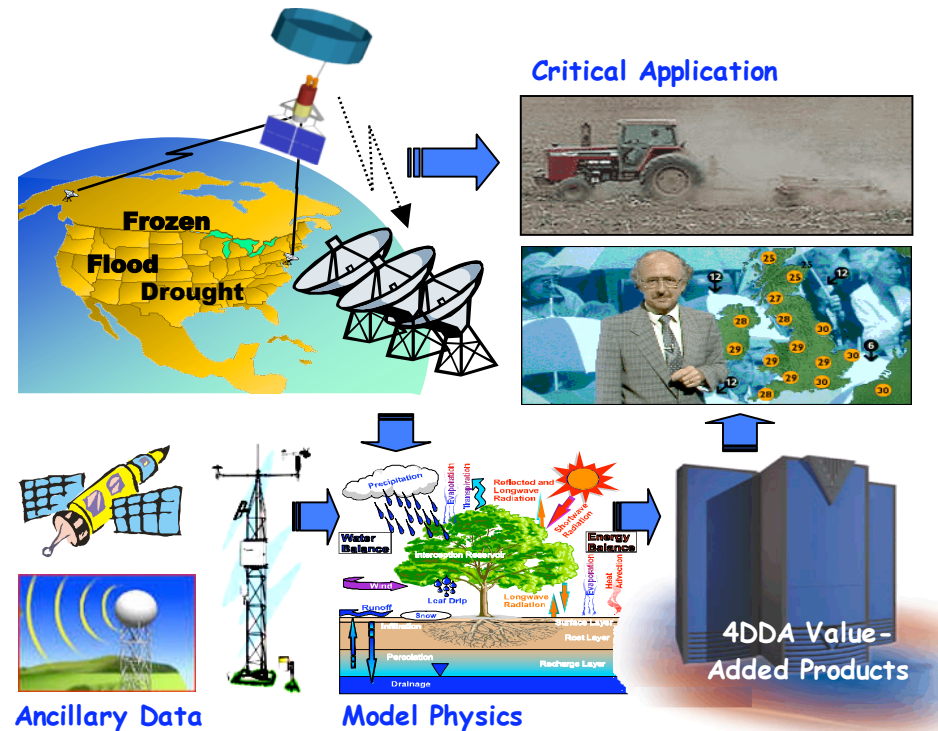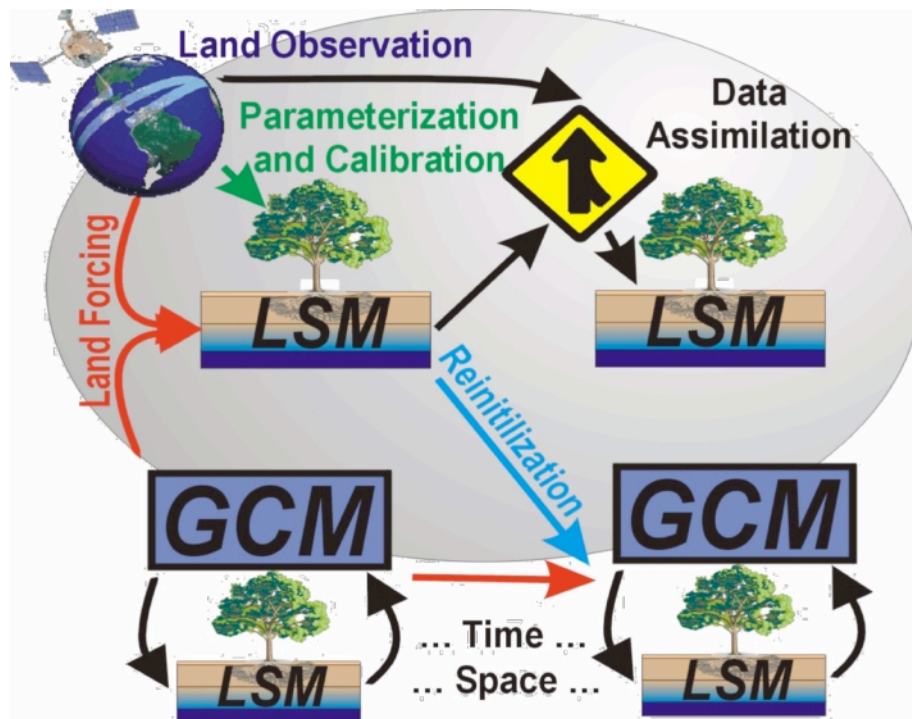
Use the adequate tool for the job…

Using a <u>systems engineering approach</u> we can merge advanced hydrologic <u>process understanding</u>, observing system <u>data</u>, and computing power to significantly improve Earth system prediction and critical water management applications

Background: Land Surface Modeling

Land Surface Prediction: Accurate land model prediction is essential to enable data assimilation methods to propagate or extend scarce observations in time and space. Based on *water and energy balance*.
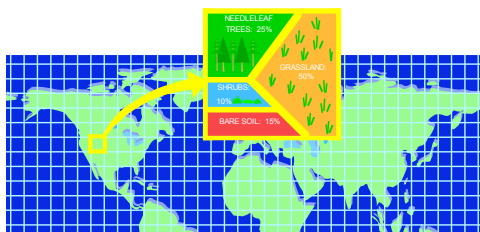
Input - Output = Storage Change

$$P + G_{in} - (Q + ET + G_{out}) = \Delta S$$

$$R_n - G = L_e + H$$

Mosaic (Koster, 1996):
- Based on simple SiB physics.
- Subgrid scale "mosaic"

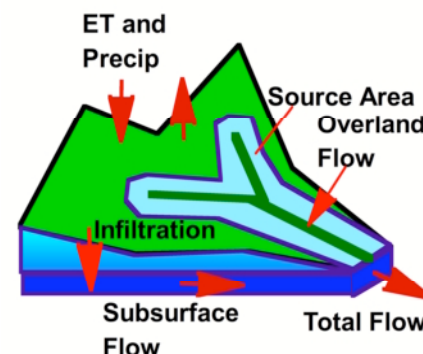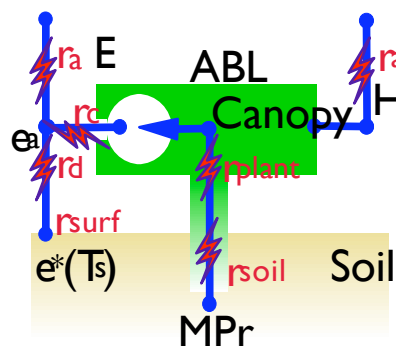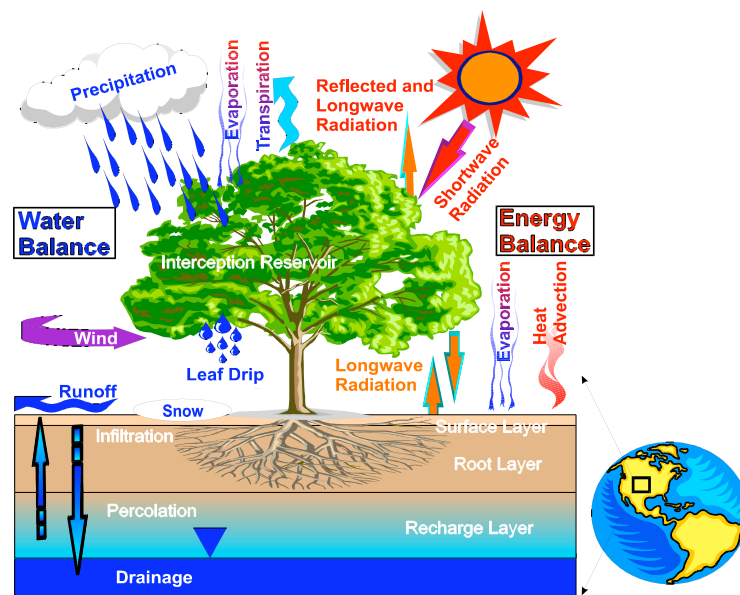**CLM** (Community Land Model, ~2003):
- Community developed "open-source" model.
- 10 soil layers, 5 layer snow scheme.

Catchment Model (Koster et al., 2003):
- Models in catchment space rather than on grids.
- Uses Topmodel concepts to model groundwater

NOAA-NCEP-Noah Model (NCEP, ~2004):
- Operational Land Surface model.

Also: vic, bucket, SiB, etc.

Land Surface Observation

Off-line LDAS

Forcing
- Precipitation
- Wind
- Humidity
- Radiation
- Air Temperature

Calibration

Parameters
- Soil Properties
- Vegetation Properties
- Elevation & Topography
- Subgrid Variation
- Catchment Delineation
- River Connectivity
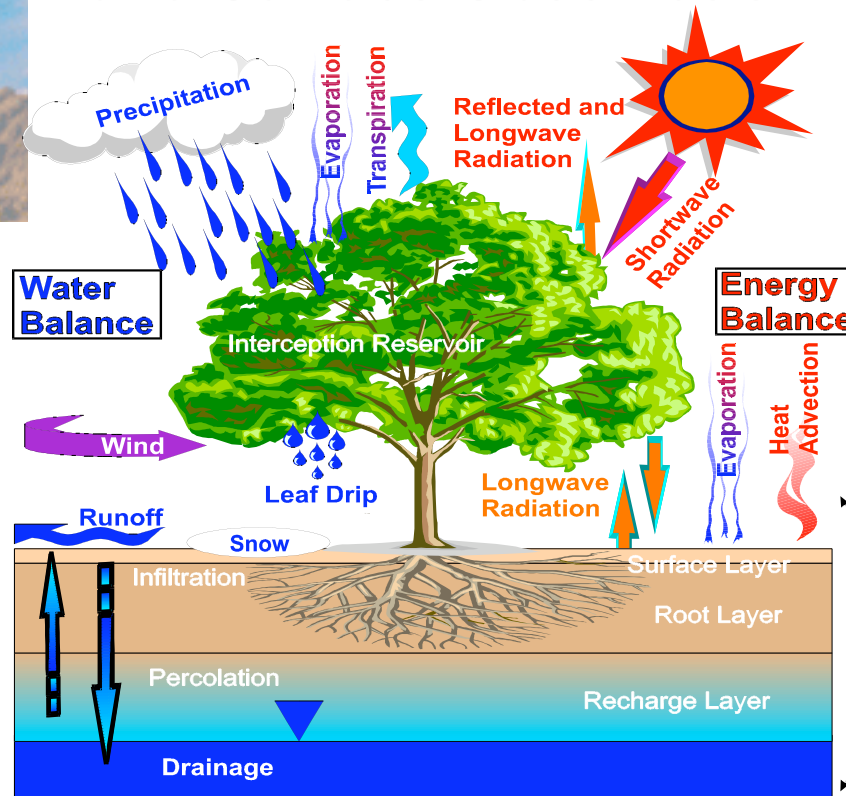
Validation

Fluxes
- Evapotranspiration
- Sensible Heat Flux
- Radiation
- Runoff
- Drainage

Assimilation

States
- Soil Moisture
- Temperature
- Snow
- Carbon
- Nitrogen
- Biomass

Precipitation
Evaporation
Transpiration
Reflected and Longwave Radiation
Shortwave Radiation

Water Balance
Energy Balance

Interception Reservoir

Wind

Leaf Drip

Longwave Radiation
Evaporation
Heat Advection

Runoff
Snow
Infiltration
Surface Layer
Root Layer

Percolation
Recharge Layer

Drainage

Soil Moisture
Snow, Ice, Rainfall

Radiation forcing
Vegetation
Snow

The availability of new _observations strongly motivates advances_ in understanding, prediction, and application.
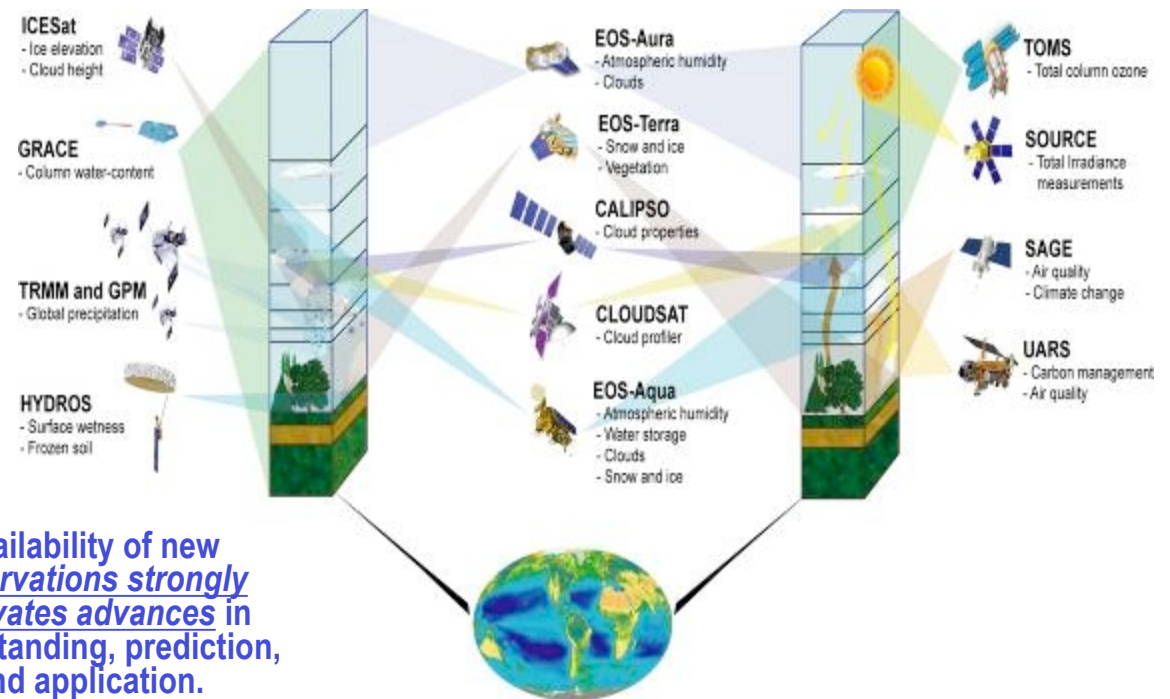
| Class	Observation	Technique	Example Platform	Temporal	Spatial
Land Parameters	Leaf area and greenness	optical/IR	AVHRR, MODIS, NPOESS	weekly	1km
	Albedo	optical/IR	MODIS, NPOESS	weekly	1km
	Emissivity	optical/IR	MODIS, NPOESS	weekly	1km
	Vegetation structure	lidar	ICESAT, ESSP lidar mission	weekly-monthly	100m
Land Forcings	Topography	in-situ survey, radar	GTOPO30, SRTM	episodic	30m–1km
	Wind profile	radar			
	Air Humidity and temperature	IR, MW	TOVS, GOES, AVHRR, MODIS, AMSR	hourly-weekly	5 km
	Near-surface radiation	optical/IR	GOES, MODIS, CERES, ERBS, etc.	hourly-weekly	1km
Land States	Precipitation	microwave/IR	TRMM, GPM, SSMI, GEO-IR, etc.	hourly-monthly	10km
	Temperature	IR, in-situ	IR-GEO, MODIS, AVHRR, TOVS	hourly-monthly	10m-4km
	Thermal anomalies	IR, NIR, optical	AVHRR, MODIS, TRMM	daily-weekly	250m–1km
	Snow cover and water	optical, microwave	SSMI, TM, MODIS, AMSR, AVHRR, etc.	weekly-monthly	1km
	Freeze/thaw	radar	Quickscat, HYDROS, IceSAT, CryoSAT	weekly	3km
	Total water storage	gravity	GRACE	monthly	1000km
	Soil moisture	active/passive microwave	SSMI, AMSR, HYDROS, SMOS, etc.	3-30 day	10-100 km
Land Fluxes	Evapotranspiration	optical/IR, in-situ	MODIS, GOES	hourly-weekly	10m-4km
	Solar radiation	optical, IR	MODIS, GOES, CERES, ERBS	hourly-monthly	
	Longwave radiation	optical, IR	MODIS, GOES	hourly-monthly	10m-4km
	Sensible heat flux	IR	MODIS, ASTER, GOES	hourly-monthly	10m-4km

Land Surface *Data Assimilation*

Obs + 4DDA + Model → Improved products, predictions, understanding
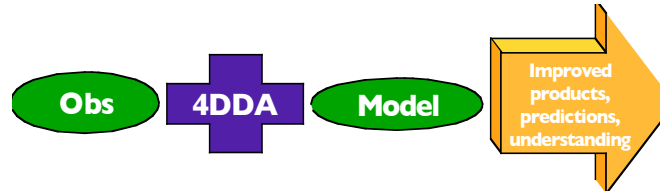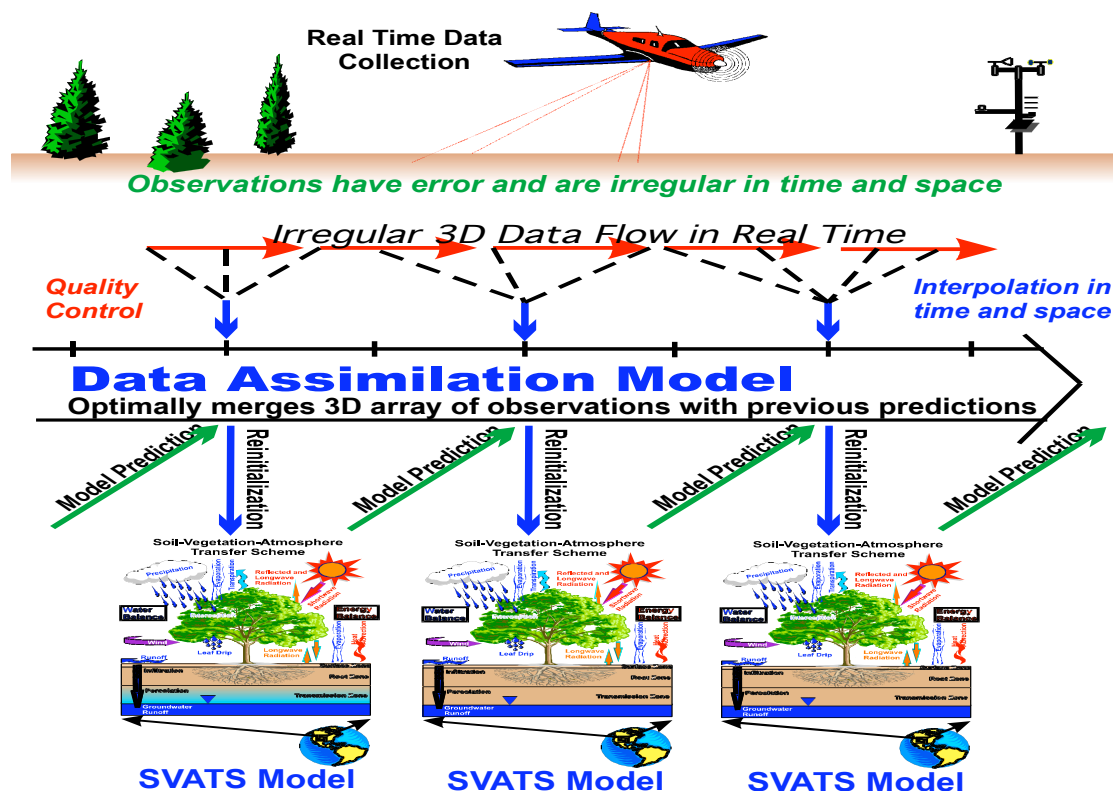
Data Assimilation merges observations & model predictions to provide a superior state estimate.

$$\partial x / \partial t = dynamics + physics + \Delta x$$

Hydrologic State or storage observations (***temperature, snow, moisture***) are integrated with models.

Real Time Data Collection

Observations have error and are irregular in time and space

Data Assimilation Methods: Numerical tools to combine disparate information.

1. **Direct Insertion, Updating, or Dynamic Initialization:**
2. **Newtonian Nudging:**
3. **Optimal or Statistical Interpolation:**
4. **Kalman Filtering: EKF & EnKF**
5. **Variational Approaches - Adjoint:**

Irregular 3D Data Flow in Real Time

Quality Control

Interpolation in time and space

Data Assimilation Model
Optimally merges 3D array of observations with previous predictions

Model Prediction — Reinitialization — Model Prediction — Reinitialization — Model Prediction — Reinitialization — Model Prediction

Soil-Vegetation-Atmosphere Transfer Scheme

SVATS Model   SVATS Model   SVATS Model

Land Surface Data Assimilation Summary

Obs + 4DDA + Model → Improved products, predictions, understanding
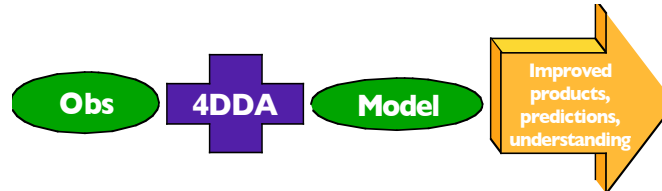
Soil Moisture Assimilation

Day-Time Soil Moisture (12:00h, July 2, 1984)

SM [m³ m⁻³]: 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
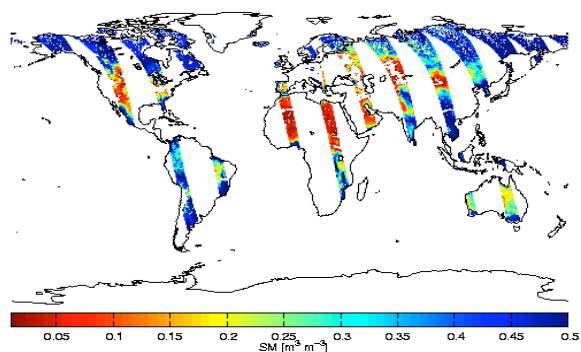
Snow Cover Assimilation

−5 −1 1 5

Theory Development

Insertion of Data into the Model

Data

Model Int...

$$\frac{\partial x}{\partial t} = dynamics + physics + \Delta x$$

EKF

update x and P

observation

x_{k-1}^+ x_k^+

P_k^-

P_{k-1}^+ x_k^- P_k^+

integrate state estimate x and error covariance P

t_{k-1} t_k t_{k+1}

EnKF

update ensemble members x^i

observation

x_{k-1}^{i+} x_k^{i-}

x_k^{i+}

integrate ensemble of states and compute sample covariance P

P_k^-

t_{k-1} t_k t_{k+1}
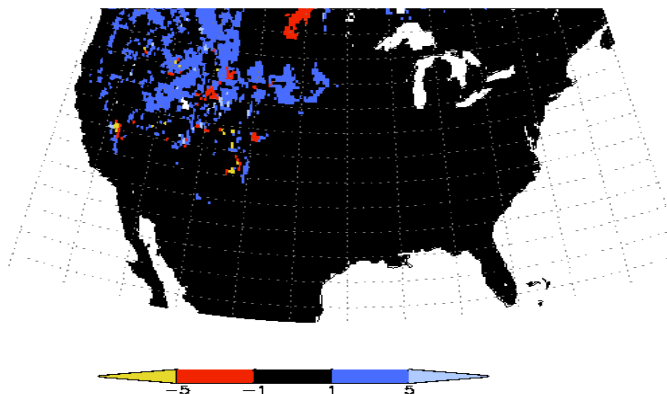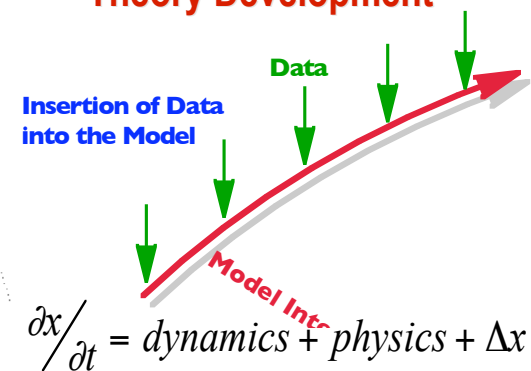
Skin Temperature Assimilation

Surface Skin Temperature (K) 34°, −100°

- OLGA
- O(P)
- O(P−IBC)
- ISCCP

Assimilation with Bias Correction

Observation

No Assimilation

Assimilation

00Z 12JUL 1992   03Z   06Z   09Z   12Z   15Z   18Z   21Z   00Z 13JUL
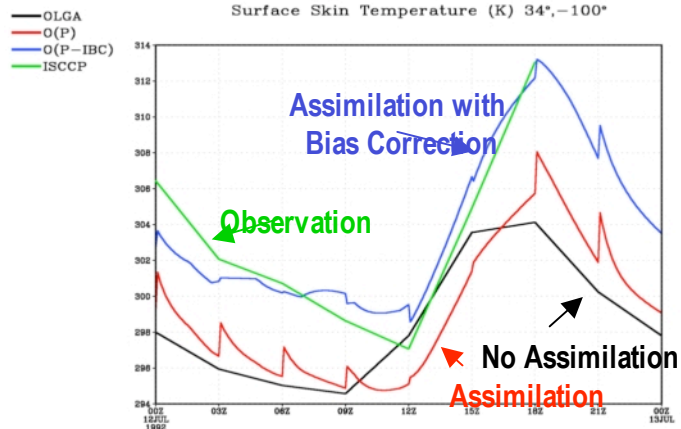
Snow Water Assimilation

SSM/I Snow Observation

0 2.5 5 10 30 40 50 75 125 150 175 250
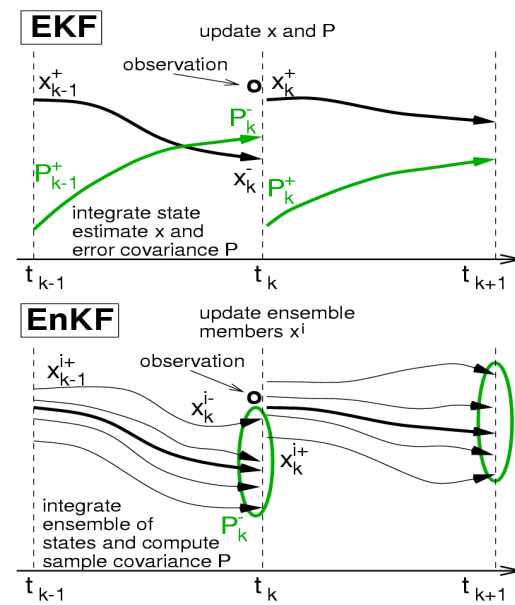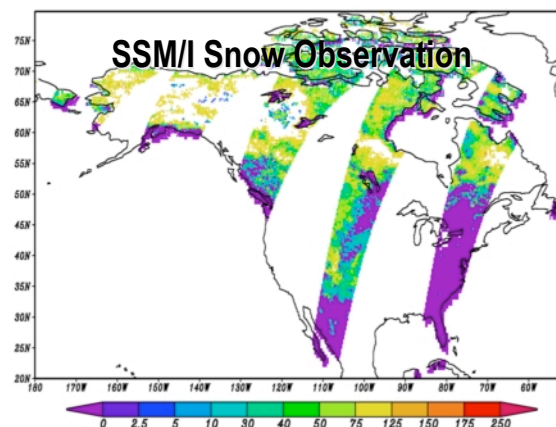
1. Introduction: What is LIS?

- A high-resolution land surface modeling system for mission planning, level-4 product generation and Earth-Sun system modeling;

- High-performance parallel computing software that enables near-real time modeling at the scale of Earth Observing System-era observations;

- An advanced data management system with Internet technologies;

- High-quality software technology with a strong, expanding user base

Missions   **Science**

LIS Impacts

Technology   **Quality of life**
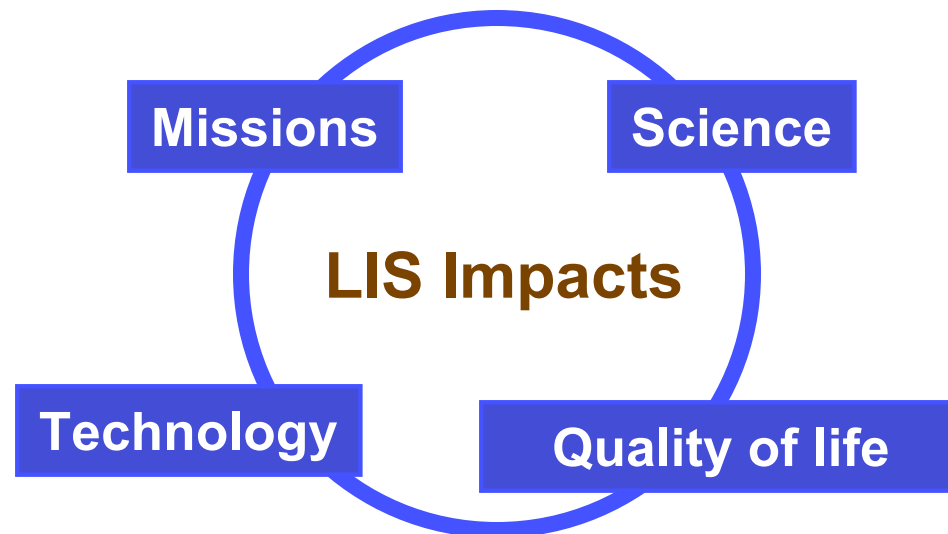
1. Introduction:
LIS System Architecture
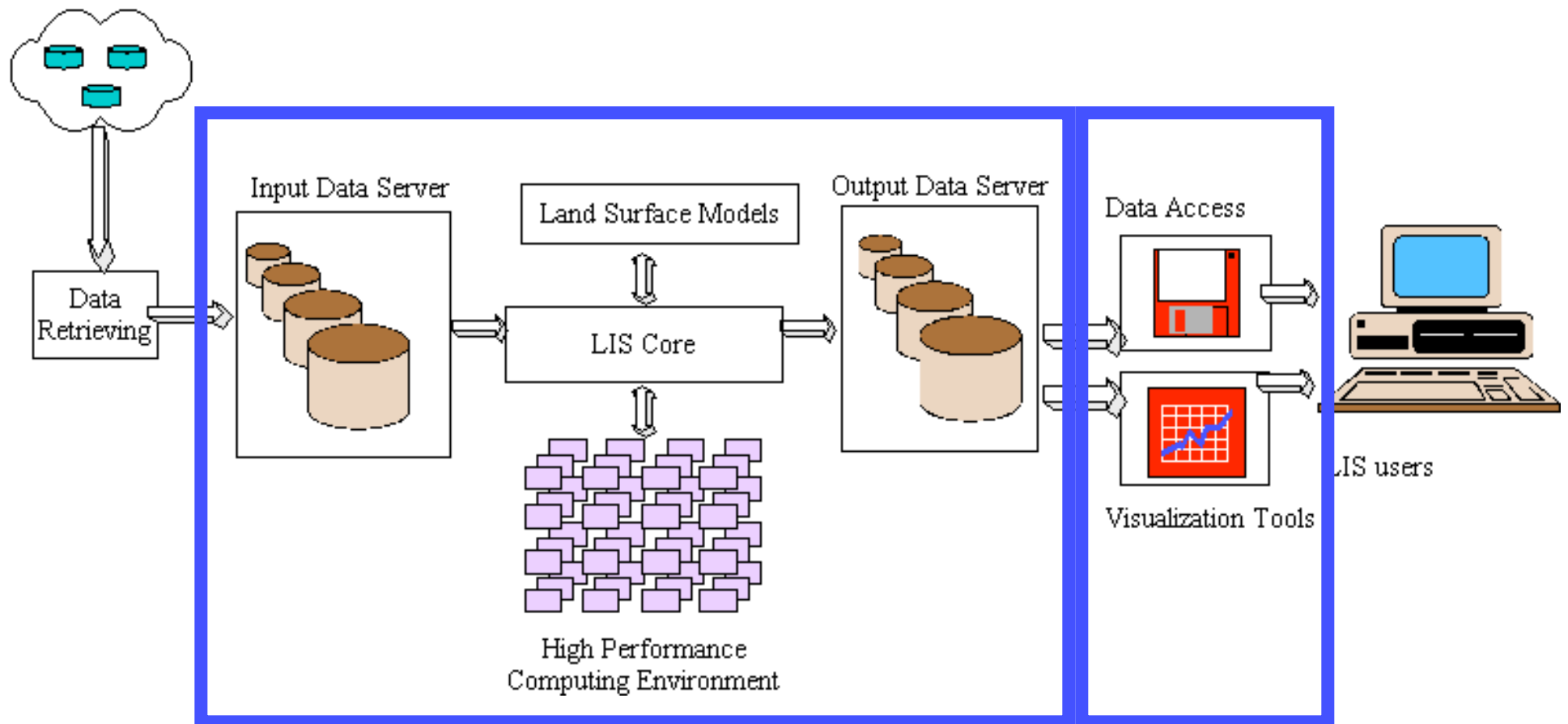
1. LIS Today

Execution and Job management GUI
- **Running on LIS Beowulf cluster at GSFC**
- **Can also run locally on laptop**

ORANGE/waiting   YELLOW/running   GREEN/done

Every box contains 200 thousand points
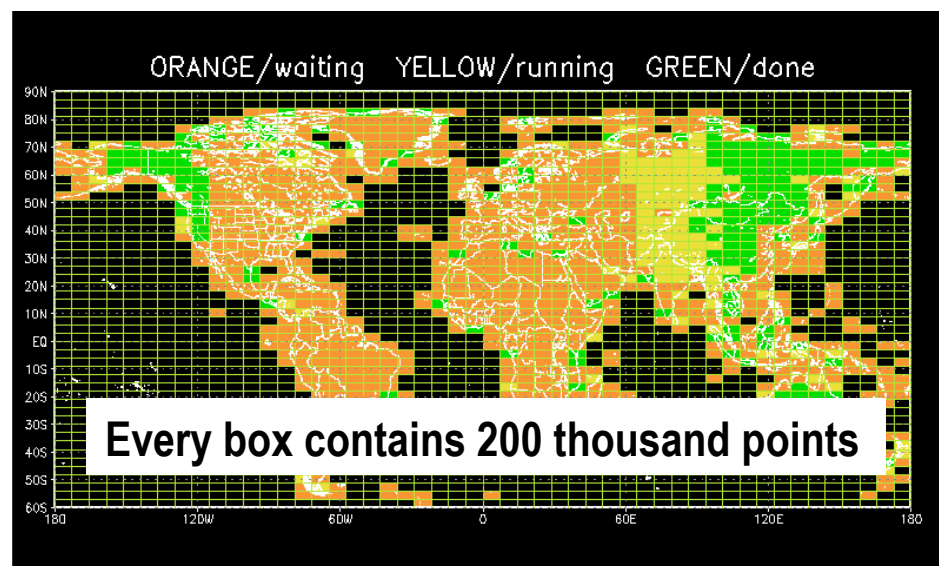
Resolution	1/4 deg	1 km
Land Grid Points	2.43E+05	1.44E+08
Disk Space/Day (Gb)	1	800
Memory (Gb)	3	1843

TERRA
throughput=850Gb/day
=200 DVDs or 1500 CDs

2. Overview:
History and Status

• Funded by NASA Earth Science Technology Office (ESTO) Computational Technologies Project (CT) CAN for "Grand Challenge Applications" in 2002.

• LIS team from 3 GSFC branches and UMBC GEST center.

• 4 major software releases.

• Over 150,000 lines of C/Fortran90 code.

• Over 150 registered users from over 30 countries.

• 260,000 hits on website over past 12 months.

• A Linux cluster with 200 nodes built as test bed.

2. Overview:
Project Milestones

		Date
A) [Software engineering plan completed](#)		*Jun. 2002*
E) [Global LDAS Code baseline completed](#)		*Jul. 2002*
B) [FY02 Annual Report](#)		*Aug. 2002*
H) [Design policy for interoperability and community delivery](#)		*Feb. 2003*
F) [First code improvement completed](#) **(LIS V1.0)**		*Mar. 2003*
I) [Interoperability prototype tested](#) **(LIS V2.0)**		*Jul. 2003*
C) [FY03 Annual Report](#)		*Aug. 2003*
G) [Second code improvement completed](#) **(LIS V3.0)**		*Feb. 2004*
J) [Full interoperability demonstrated using improved codes](#)		*Jul. 2004*
K) [Customer delivery accomplished](#) **(LIS V4.0)**		*Feb. 2005*
D) [Final Report delivered](#)		*May. 2005*

2. Overview: LIS Science and Data Flow

Inputs

Physics

Outputs

Applications

Topography, Soils

Land Cover and Vegetation (MODIS, AMSR, TRMM, SRTM)

Meteorology Modeled & Observed (TRMM, GOES, Station)

Observed Land States (Snow, ET, Soil Moisture, Groundwater, Carbon, etc.)

Land Surface Models (LSM) Physical Process Models Noah, CLM, VIC, SiB2, Mosaic, Catchment, etc.

Data Assimilation Modules (EnKF, EKF) Physical Space Analysis System (PSAS) 3-D VAR Rule-based

Energy Fluxes: Le & H

Biogeo-chemistry: Carbon, Nirtogen, etc.

Water Fluxes: Runoff

Surface States: Moisture, Carbon, Ts

Water Supply & Demand,

Agriculture, Hydro-Electric Power, Endangered Species, Water Quality

Improved Short Term & Long Term Predictions

(Peters-Lidard, Houser, Kumar, Tian, Geiger)

3. Impact: NASA Missions and Science

NASA missions:

- Hydrosphere States Mission (Hydros) level 4 products
- Gravity Recovery and Climate Experiment (GRACE) science team
- Tropical Rainfall Measurement Mission (TRMM) science team
- Aqua Advanced Microwave Scanning Radiometer-EOS (AMSR-E) science team
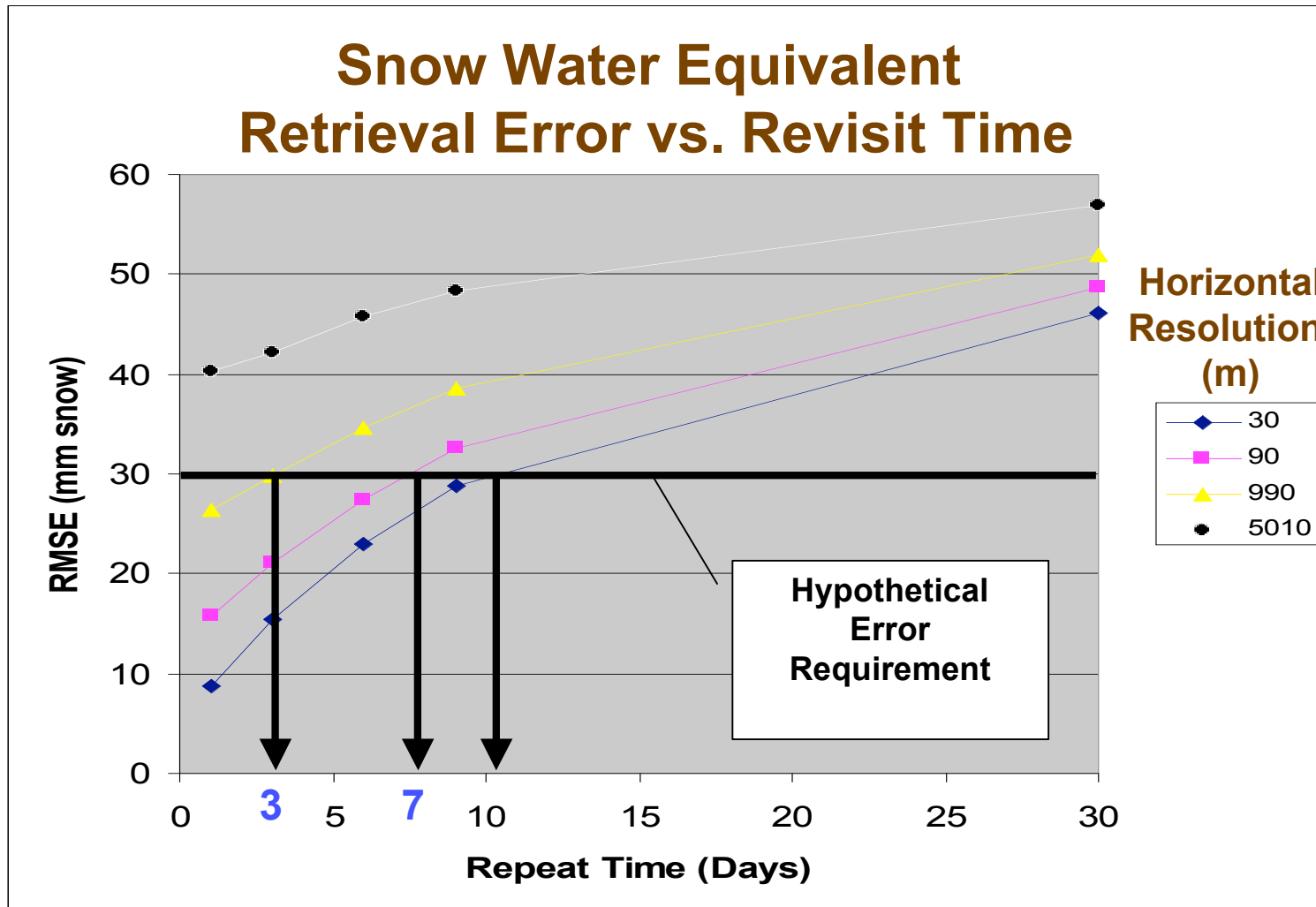- Cold Land Processes Pathfinder ESSP-4 Proposal Planning

NASA Earth-Sun science:

- The Global/National Land Data Assimilation System (GLDAS/NLDAS)
- ESTO/Advanced Information Systems Technology (AIST)
- Goddard Modeling and Assimilation Office (GMAO)

HYDROS provides the first global view of the Earth's changing soil moisture and surface freeze/thaw conditions, enabling new scientific studies of global change and atmospheric predictability, and making new hydrologic applications possible.

3. Impact: NASA Mission Planning
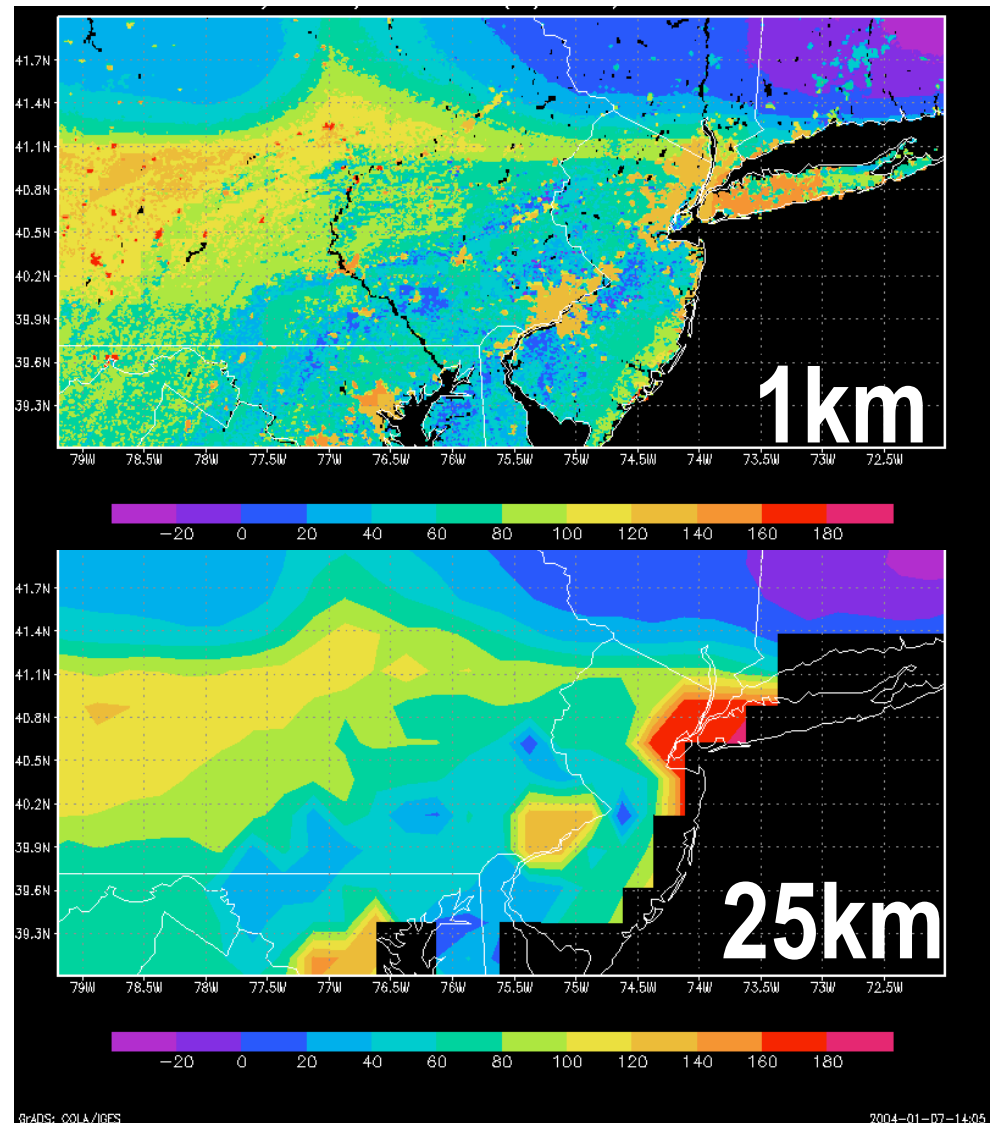

Snow Water Equivalent
Retrieval Error vs. Revisit Time

3. Impact: Science

High-resolution (enabled by LIS):
-See small, medium, large cities
-Demonstrate impact of EOS-era observations (e.g., MODIS)
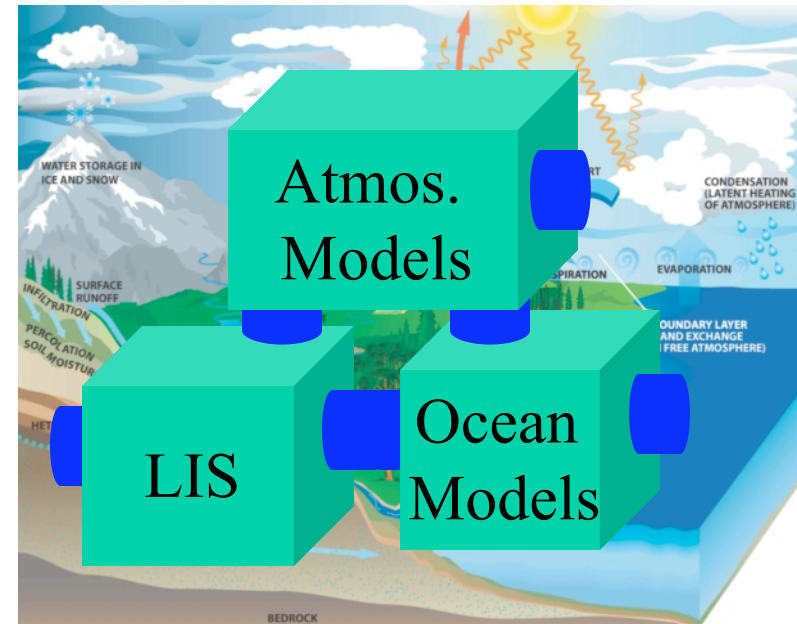

Traditional resolution (before LIS):
-See only large size urban areas
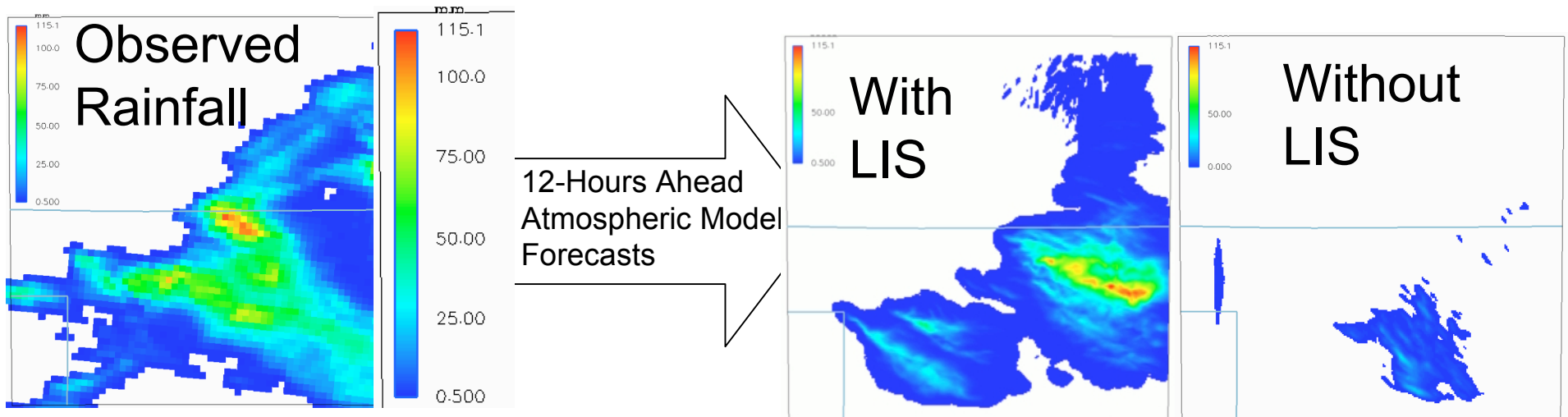-Overpredict magnitude of heat island (nonlinear averaging)

3. Impact: Coupled Earth System Modeling

Interoperability with standards:
- **The Earth System Modeling Framework (ESMF)**
- **Assistance for Land Modeling Activities (ALMA)**

LIS Impact Example: Coupling to a Weather Model

Observed Rainfall

12-Hours Ahead Atmospheric Model Forecasts

With LIS

Without LIS

3. Impact: LIS in the News

ESDCD *news*

Earth and Space Data Computing Division
Earth Sciences Directorate, Goddard Space Flight Center

Code 930 • http://esdcd.gsfc.nasa.gov

Summer 2004 ESDCD News Home > Data Drives Land Surface Modeling at GSFC

Computational Technologies Project

Data Drives Land Surface Modeling at GSFC

When the Land Information System (LIS) investigation set out to run the w_
land surface model, they quickly realized that a shared supercomputer ce_
needs. A global run at that resolution, as completed this past July, produ_
each simulated day.

"At 1 kilometer, we can't get the data over there and back fast enough," sa_
Peters-Lidard, who is LIS project manager and co-principal investigator w_
can buy the biggest computer in the world, but if you can't connect the co_
useful."

To serve such a data-intensive application, the LIS team built their model_
customized Beowulf cluster with 200 processors. Several hardware and _
empowered LIS "to model the land surface at the scale of NASA observat_
like MODIS and TRMM to future platforms like HYDROS and GPM," Peters_
capability, LIS realistically predicts the water and energy cycles, including_
plants and soil, and heat storage in the ground.

*A 200-proce_*
*the Land Info_*
*model the gl_*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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+ News

FEATURE

2004 Earth Feature Story

Special: FROM NEIGHBORHOODS TO GLOBE, NASA LOOKS AT LAND

Satellites and computers are getting so good, that now they can help study human activity on scales as local as ones own neighborhood, and may answer questions concerning how local conditions affect global processes, like water and energy cycles.

NASA's Land Information System (LIS) uses computer models to predict impacts that cities and other local land surfaces might have on regional and global land and atmospheric processes. Dr. Christa Peters-Lidard, Co-Principal Investigator and Project Manager for LIS, at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Md., gave a presentation on LIS this week at the annual meeting of the American Meteorological Society in Seattle.

Until recently, scientists could not model detailed, local interactions between land an_
scale because satellites did not provide a close enough view of Earth, and compute_

Texas

Click on image to e_
Houston Metro Area_

The Houston metro
area in red. Credit: N_
Systems

4. Users and Beneficiaries:
(current, potential)

National agency users:

National Centers for Environmental Prediction (5, 100)

US Army Corps of Engineers (2, 1000)

Air Force Weather Agency (2, 200)

US Environmental Protection Agency (3, 100)

Bureau of Reclamation (2, 50)

Commercial users:

Baron Advanced Meteorological Systems (BAMS) (5, 100)

University users:

e.g., Princeton, Colorado State U., (80, 1000)

International program users:

WMO Coordinated Enhanced Observing Period (CEOP)

WCRP Global Energy and Water Cycle Experiment (GEWEX)

Over 100 *unique* registered organizations from over 30 countries …potentially impacting millions of users

Impact

Over 100 registered users organizations from over 30 countries and still growing …

#	Hits		Files		KBytes		Country
1	6852	29.51%	3501	26.87%	139390	0.08%	US Commercial
2	3677	15.84%	2845	21.84%	4231983	2.57%	Unresolved/Unknown
3	3044	13.11%	1822	13.98%	9259070	5.62%	US Government
4	2979	12.83%	1762	13.52%	1992364	1.21%	Network
5	2285	9.84%	2110	16.19%	84378734	51.18%	Sweden
6	1392	6.00%	1153	8.85%	29713125	18.02%	Netherlands
7	1199	5.16%	849	6.52%	17305011	10.50%	US Educational
8	393	1.69%	373	2.86%	17641006	10.70%	Non-Profit Organization
9	233	1.00%	196	1.50%	143094	0.09%	Japan
10	165	0.71%	134	1.03%	662	0.00%	Canada
11	116	0.50%	109	0.84%	292	0.00%	Finland
12	93	0.40%	30	0.23%	100	0.00%	Turkey
13	91	0.39%	50	0.38%	11265	0.01%	United Kingdom
14	56	0.24%	47	0.36%	3190	0.00%	Singapore
15	52	0.22%	33	0.25%	1837	0.00%	US Military
16	49	0.21%	22	0.17%	165	0.00%	Australia
17	48	0.21%	5	0.04%	21	0.00%	Jordan
18	45	0.19%	30	0.23%	3578	0.00%	Poland
19	42	0.18%	35	0.27%	4735	0.00%	Argentina
20	42	0.18%	42	0.32%	131	0.00%	Czech Republic
21	35	0.15%	19	0.15%	162	0.00%	Switzerland
22	29	0.12%	21	0.16%	2446	0.00%	Belgium
23	25	0.11%	19	0.15%	3869	0.00%	Germany
24	22	0.09%	7	0.05%	33	0.00%	Malaysia
25	19	0.08%	14	0.11%	2357	0.00%	Italy
26	18	0.08%	13	0.10%	2377	0.00%	Spain
27	18	0.08%	15	0.12%	134	0.00%	Hong Kong
28	18	0.08%	14	0.11%	111	0.00%	Portugal
29	15	0.06%	5	0.04%	18	0.00%	Brazil
30	14	0.06%	5	0.04%	1542	0.00%	Taiwan

Top 30 of 52 Total Countries

Example User Feedback

"The LIS software has been developed using *industrial standard software development procedures and best practices recommended by CT*. It is built around and deploys high-performance computing technology such as *pool-of-processors* and creative adaptation of *Peer-to-Peer (P2P) technology* for high performance data replication and delivery that not only allow a significant increase in the resolution of the land data assimilation product produced but also allow creation of these products at an unprecedented rate. The fact that all this *runs well on inexpensive pc-clusters makes it breakthrough technology*."
– Dr. Shujia Zhou, NASA ESTO/CT

"One of the creative new feature I like is that user can choose among *different models incorporated in the LIS* system. *Flexibility in design* running domain at run time is another innovative solution I like most."
– Prof. Linus Zhang, Lund University, Sweden

4. Potential Users:

DOD and Related Contractors:

US Army Corps of Engineers: **Funding the use of LIS in their Army Remote Moisture System for potential deployment to 250 Warrant Officer groups worldwide as part of Digital Terrain Support System and Future Combat System**

Air Force Weather Agency: **Funding the use of LIS to replace their Agricultural Meteorological (AGRIMET) Modeling system, used by thousands worldwide to forecast crop yields and provide weather input for DoD.**

Weather and Environmental Sector:

Baron Advanced Meteorological Systems (BAMS): **Funding two UMBC/GEST LIS developers to transition LIS to flood forecasting applications in Romania as part of the Lockheed Martin Destructive Water Abatement (DESWAT) project**

Riverside Technologies, Inc.: **Has contacted and visited us to discuss applications in NOAA/NWS**

National Weather Service (NWS): **Currently funded to use LIS to advance flood forecasting capabilities using NASA Observations**
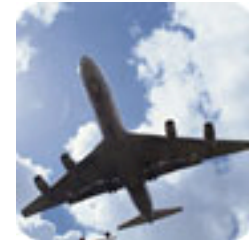
Impact

More potential applications:

Water Management

Public Health

Energy Forecasting

Aviation Safety
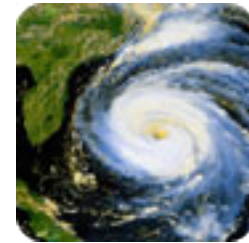
Carbon Management

Homeland Security

Coastal Management

Disaster Preparedness

Agricultural Competitiveness

Invasive Species

Community Growth

Air Quality

5. Software Description

5.1 Usability

5.2 Quality

5.3 Innovation

5.1 Usability: Documentation
and User Support

- *LIS User's Guide*
  - How to install, run
- *LIS Developer's Guide*
  - How to customize

- Public Software Engineering Documents (Quality)

- Sourceforge-based bug-tracking and help desk

LIS User's Guide

Submitted under Task Agreement GSFC-CT-2

Cooperative Agreement Notice (CAN) CAN-00OES-01

Increasing Interoperability and Performance of
Grand Challenge Applications in the Earth, Space, Life, and Microgravity
Sciences

LIS Developer's Guide

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Increasing Interoperability and Performance of
Grand Challenge Applications in the Earth, Space, Life, and Microgravity
Sciences

May 7, 2004

Version 3.0

		Date
		May 7, 2004
		November 30, 2003
		November 10, 2003
		August 14, 2003
		April 25, 2003
		March 31, 2003

History:

Revision	Summary of Changes	Date
3.0	Milestone "G" submission	May 7, 2004
2.3	LIS 2.3 code release	December 19, 2003
	Initial revison	

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

5.1 Usability: Portability

- Current supported platforms
  - Linux laptops, desktops and clusters
  - Compaq Alphas (Halem)
  - SGIs (Lomax, Chapman)
  - IBM SPs
  - Windows
  - Mac OS

- Benchmarking on Columbia (SGI Altix) now

5.1 Usability: Configurability

LIS Card File Generator

http://lis.gsfc.nasa.gov/Data/MilestoneG/cfg.html

LIS Card File Generator			Online Tutorial	

Path of Input directory:	INPUT		Path of Output directory:	OUTPUT

Input

Land Surface Model	Spatial Resolution	Base Forcing	Observed Precipitation	Observed Radiation
CLM	1/4 deg	GEOS		

Temporal Domain		Grid Type	Spatial Domain	
	Year Month Day Hour	Lat/Lon	Parameter Domain	Execution Domain

			min	max	min	max
Start:	2004 Jan 1 00					
Stop:	2004 Jan 1 00	Lat:	-60	90	-60	90
Timestep:	900 seconds	Lon:	-180	180	-180	180

Options

Restart	No	Full path of restart file:	
LAI	MODIS	Elevation Correction:	Yes
Max tiles per grid:	1	Min % to create tile:	0.05

Output

Output Forcing Variables:	No	Write output to a single file:	yes	Format:	Binary
Write parameter output:	No	Write output in a tile domain:	2-D grid		

Submit					

5.1 Usability: Job management GUI
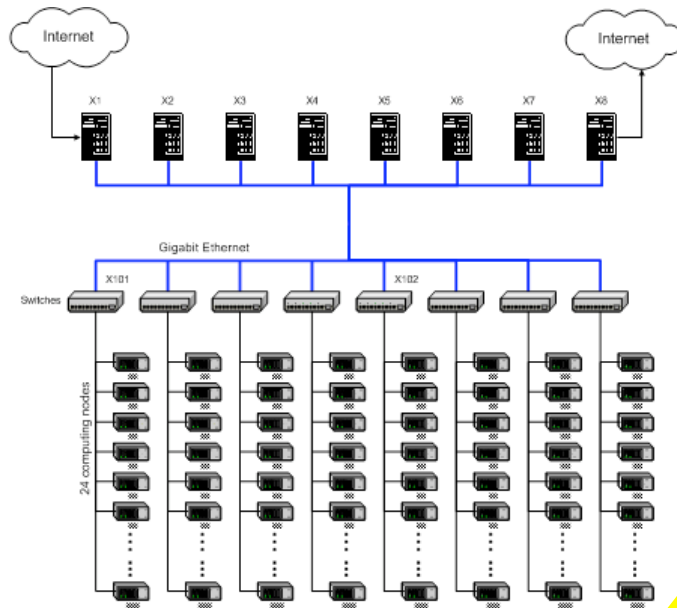
LIS Cluster
(200 nodes, ~40TB storage)

ORANGE/waiting   YELLOW/running   GREEN/done

avgsurft at (−122.395, 33.005) − (−115.195, 36.005)
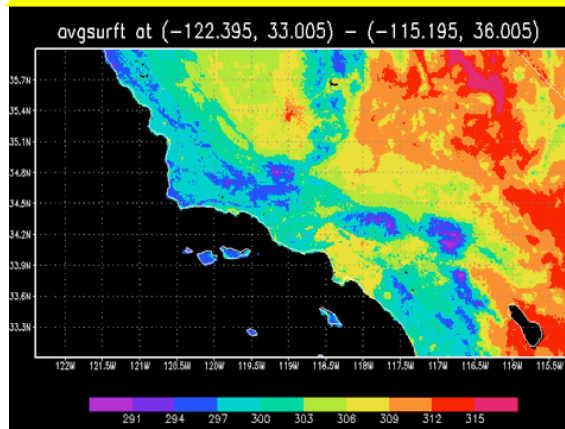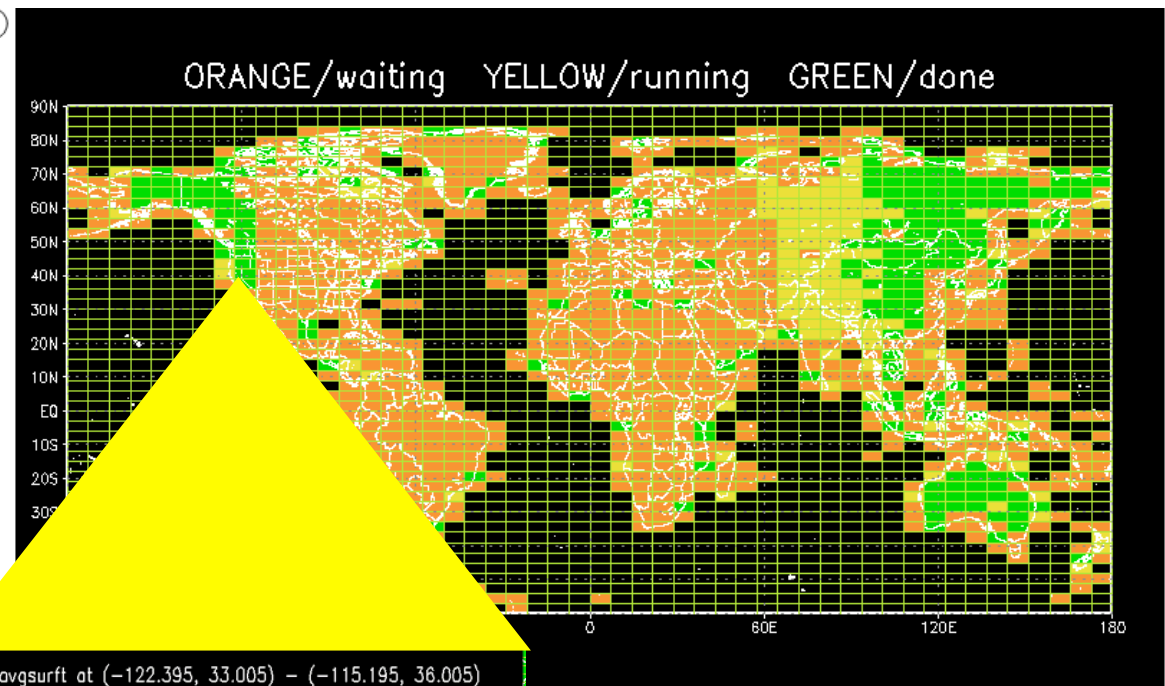
5.2 Quality: Industry-standard software engineering

Software Engineering Documents
- Publicly Available
- Reviewed/Quality Assured

Documents Reflect Process:
- Software Engineering Plan
- Requirements Document
- Requirements Traceability Matrix
- Software Design-Interoperability
- Software Design-Data Management
- Software Design-User Interface
- Code Maintenance Manual
- Test Plan
- LIS User's Guide (Usability)
- LIS Developer's Guide (Usability)

National Aeronautics and
Space Administration
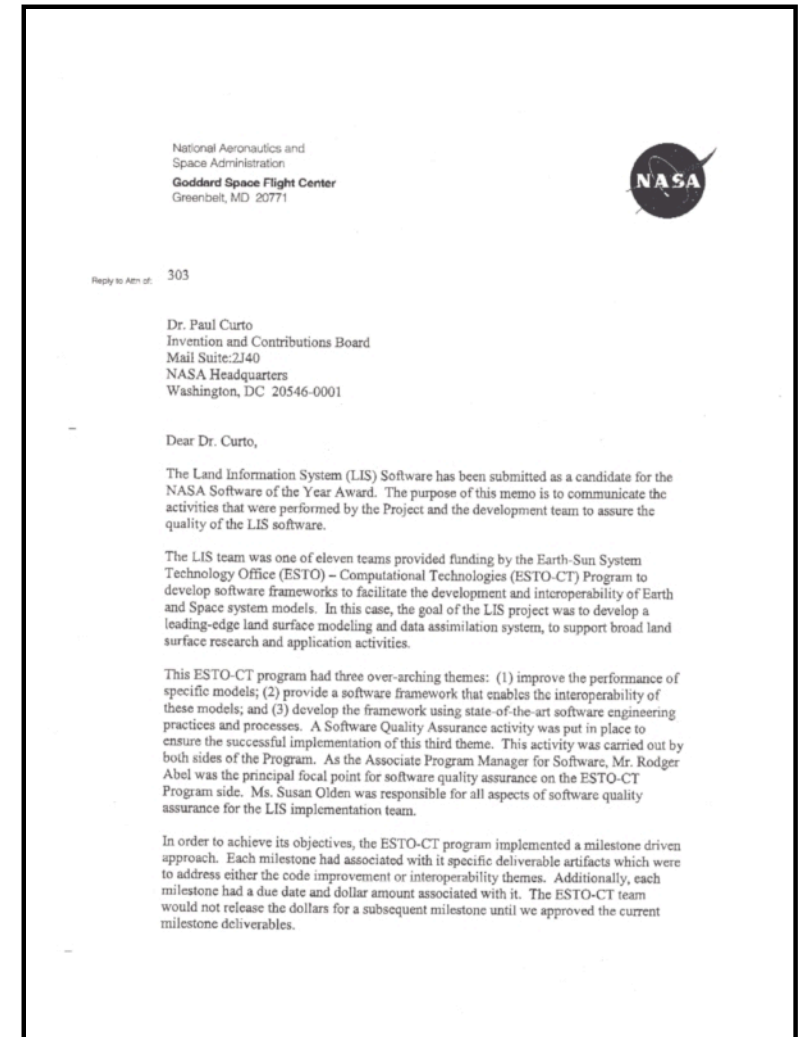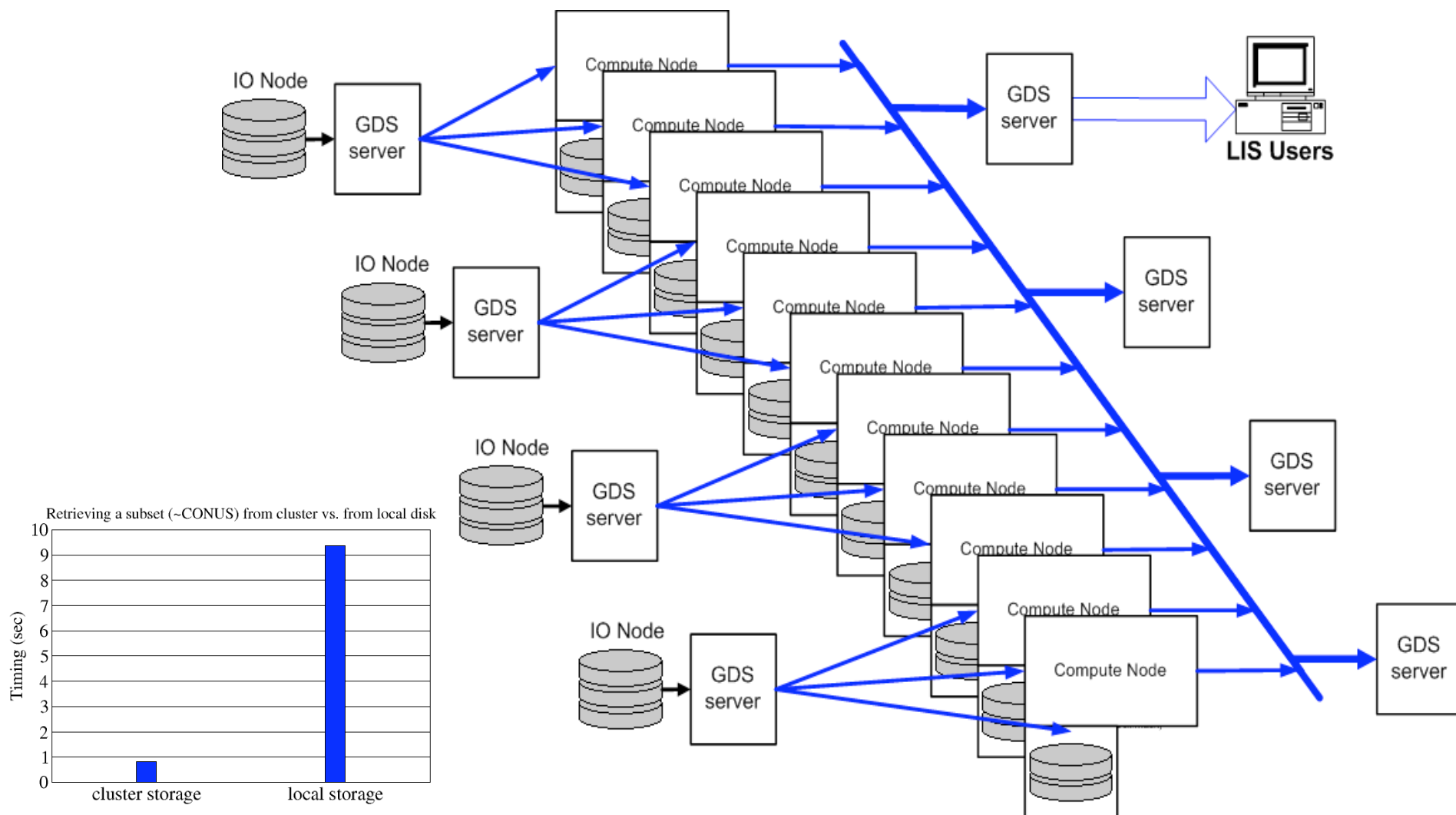**Goddard Space Flight Center**
Greenbelt, MD 20771

Reply to Attn of: 303

Dr. Paul Curto
Invention and Contributions Board
Mail Suite:2J40
NASA Headquarters
Washington, DC 20546-0001

Dear Dr. Curto,

The Land Information System (LIS) Software has been submitted as a candidate for the NASA Software of the Year Award. The purpose of this memo is to communicate the activities that were performed by the Project and the development team to assure the quality of the LIS software.

The LIS team was one of eleven teams provided funding by the Earth-Sun System Technology Office (ESTO) – Computational Technologies (ESTO-CT) Program to develop software frameworks to facilitate the development and interoperability of Earth and Space system models. In this case, the goal of the LIS project was to develop a leading-edge land surface modeling and data assimilation system, to support broad land surface research and application activities.

This ESTO-CT program had three over-arching themes: (1) improve the performance of specific models; (2) provide a software framework that enables the interoperability of these models; and (3) develop the framework using state-of-the-art software engineering practices and processes. A Software Quality Assurance activity was put in place to ensure the successful implementation of this third theme. This activity was carried out by both sides of the Program. As the Associate Program Manager for Software, Mr. Rodger Abel was the principal focal point for software quality assurance on the ESTO-CT Program side. Ms. Susan Olden was responsible for all aspects of software quality assurance for the LIS implementation team.

In order to achieve its objectives, the ESTO-CT program implemented a milestone driven approach. Each milestone had associated with it specific deliverable artifacts which were to address either the code improvement or interoperability themes. Additionally, each milestone had a due date and dollar amount associated with it. The ESTO-CT team would not release the dollars for a subsequent milestone until we approved the current milestone deliverables.

5.3 Innovation

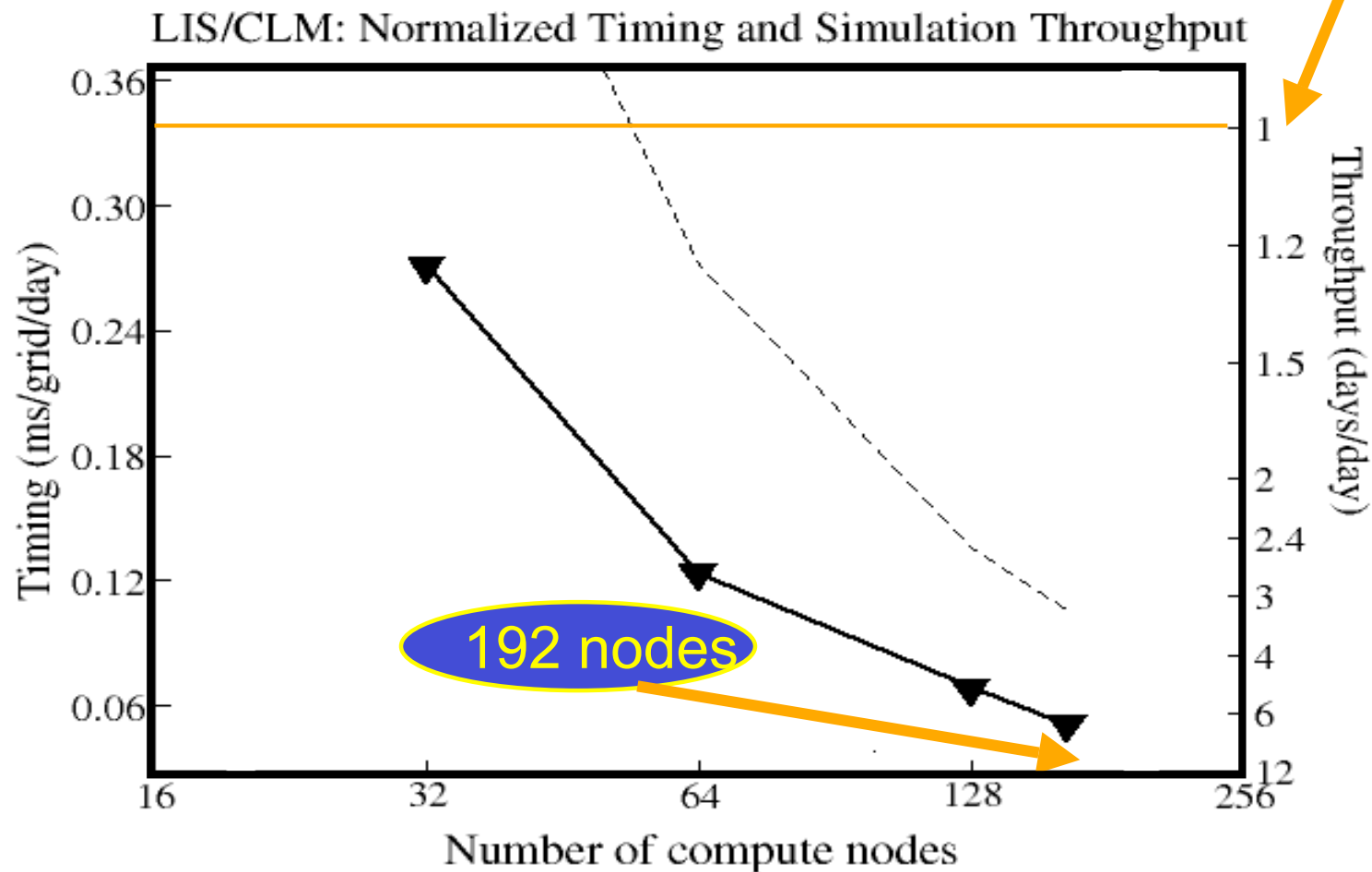**Parallel I/O with distributed data storage for high throughput with inexpensive hardware**

5.3 Innovation
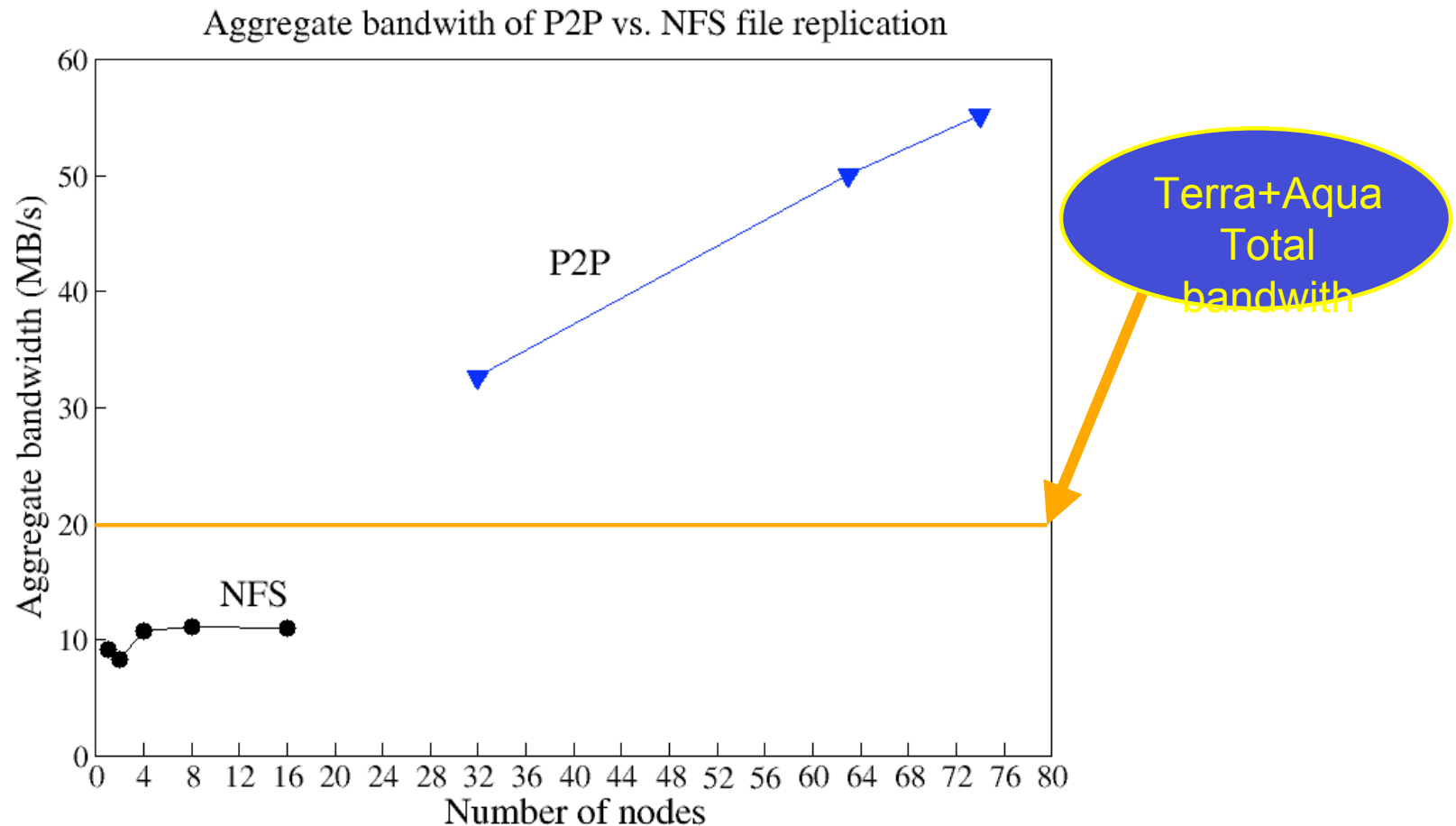
**Parallel scaling enables
Near-Real-Time operations**

Real-time: 1day/day

LIS/CLM: Normalized Timing and Simulation Throughput

192 nodes

5.3 Innovation

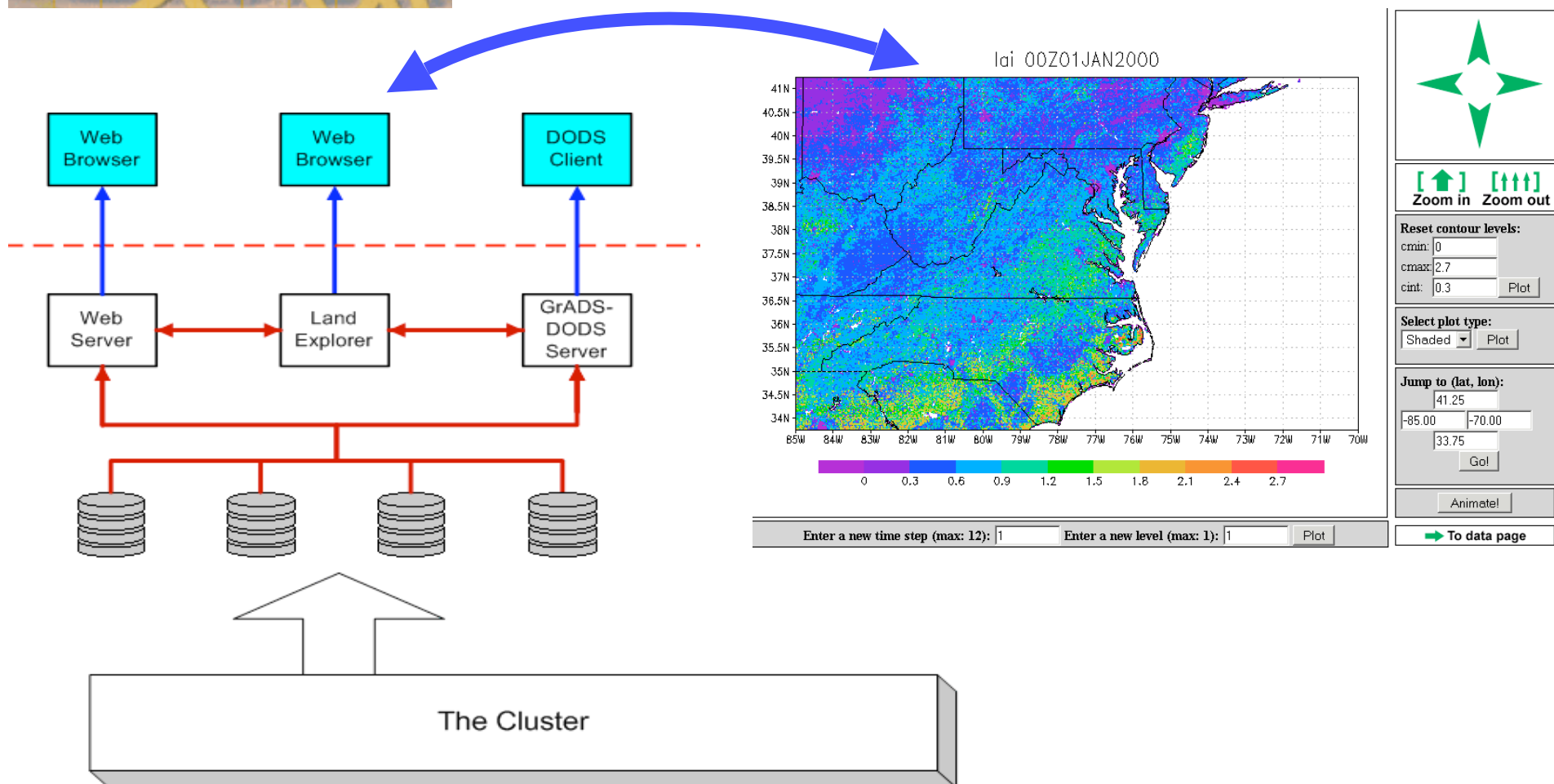**High performance, scalable data replication with peer-to-peer (P2P) technology enables use of EOS-era data in models**

Data replication performance comparison between conventional Network File System (NFS) and LIS peer-to-peer (P2P) technology.

5.3 Innovation

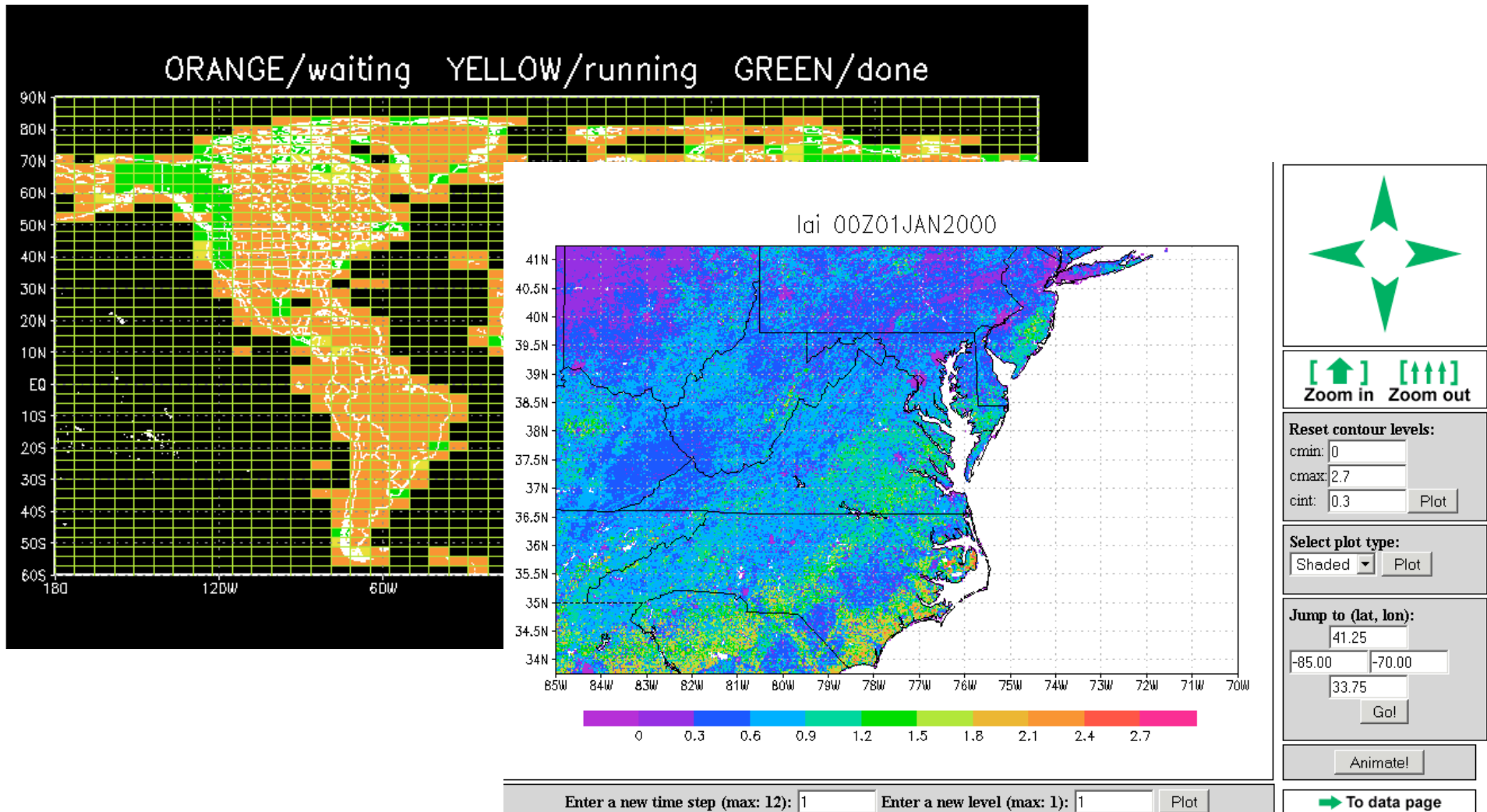**LIS data-on-demand web services for public data distribution**

LIS user interface architecture based on web services and distributed storage.
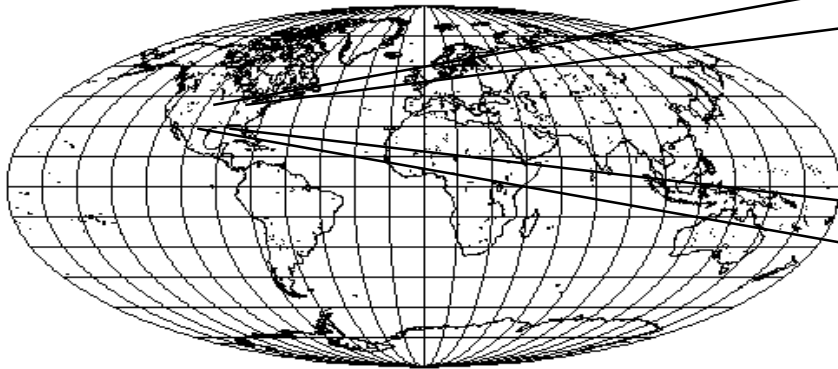
6. User Interface

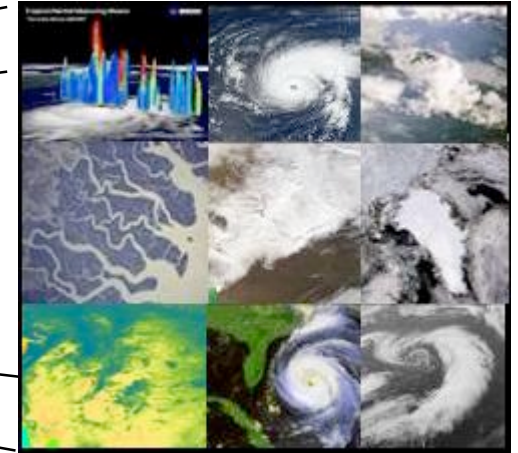- **Execution and Job management GUI**
- **Land Explorer Data Server GUI**

LIS Future: Advanced Process-Resolving Models

Climate models' grid-box representation of Earth's processes...

Each grid-box can only represent the "average" conditions of its area.

However, controlling processes of the water cycle (e.g. precipitation) vary over much smaller areas.

Developing Advanced Process-Resolving Models

- Useful prediction is critical – it is the link to stakeholders.

- We must move towards a new paradigm of climate models that produce useful weather-scale, process-scale, and application-scale prediction of local extremes (not just mean states).

- We must more fully constrain climate models with observations, to improve their realism and believability.

7. Summary

- **LIS makes significant contributions to**
    - NASA missions and projects
    - Earth-Sun sciences
    - National agency and international applications
    - General public
- **LIS innovates**
    - the scientific modeling and prediction process
    - the mission planning process
    - parallel computing with cluster technologies
    - data management with Internet technologies
- **LIS is sophisticated but easy to use**
    - portable, interoperable and configurable
    - extensive documentation
    - GUI and community support